

Zraniteľnosť dopravnej infraštruktúry v súvislosti s konceptom mesta odolného pri katastrofách

Vulnerability of Transport Infrastructure in the Context of Disaster Resilient City Concept

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Abstrakt

Trvalý rozvoj a fungovanie mestských služieb závisí aj od infraštruktúry, ktorá je v mestách. Pochopenie rozdielov v odolnosti a zraniteľnosti infraštruktúry je dôležité pre bezpečnosť mesta. Pozornosť je venovaná infraštruktúre, najmä dopravnej, a jej zraniteľnosti. Niektoré typy infraštruktúry alebo niektoré špecifické prvky infraštruktúry môžu byť, viac alebo menej, zraniteľné ako ostatné. Na základe uvedených skutočností sa príspevok zameriava na hodnotenie zraniteľnosti mestskej infraštruktúry voči účinkom katastrof ako súčasti koncepcie odolného mesta. Vytvorený návrh hodnotenia zraniteľnosti infraštruktúry má slúžiť pre potreby kritickej infraštruktúry.

KLúčové slová

Zraniteľnosť, mesto odolné pri katastrofách, dopravná infraštruktúra.

Abstract

The sustainability development and operation of the city services are dependent on city serviceable infrastructure. The understanding of different infrastructures resilience and vulnerabilities is important for the city security. Focus in article will be paid on infrastructure, mainly transport infrastructure and its vulnerability. Some infrastructure types or some specific infrastructure elements can be more or less vulnerable than the others. Following mentioned facts the paper focuses on assessment of the city infrastructure vulnerability to the effects of disasters as a part of the resilient city concept. The proposed assessment is intended to be applied to the critical infrastructure.

Keywords

Vulnerability, Disaster resilient city, Transportation infrastructure.

Introduction

Based on the statistics and literature review [1 - 4] it can be argued that there is an increasing trend of disasters occurrence. At the same time due to disaster higher intensity the more severe impacts can be observed. As a trigger of such events were identified mainly climate change aspects [1 - 3] current disasters development several guidelines (directives) and measures have been adopted by the organizations of international crisis management. The climate change was address in the Paris climate Agreement (2016) and in frameworks Sendai (2015), Hyogo (2005) and Yokohama (1994). These documents are focused mainly on the issues of society resilience as a concept of civil protection.

The resilient city concept is based on anticipation, mitigation and reduction of physical, economic and social impacts of disasters within a city (mainly for natural disasters with association on climate change but it is applicable also for manmade or intentional ones - we will consider natural disasters only). This is done by creating an appropriate conditions for dealing with such situations through application of various measures e.g. ensuring organized services for whole community (from common to rescue); adhering sensible building codes and spatial planning (without informal settlements built on flood plains or steep slopes); incorporating monitoring and early warning systems to protect individuals (residents), infrastructure, community assets, environment, and cultural heritage; preparing and implementing of recovery strategies, etc. [5].

Cities are dense and complex systems. They are characterized by intense, regular interactions that are structured into identifiable activity areas, or in key resource management or mobility sub-systems. In resilient city concept are divided into several components [6]: health, environmental, social/cultural, infrastructure, education, disasters, economic. In this paper we deals with "infrastructure" part and closely with its sub-part transportation infrastructure.

The character of cities as complex place-based systems is very different to that of lower-density rural areas where activities are more spatially separated and interactions are less intense. In the urban environment in particular, the resilience of a place-based system is only as great as its weakest part [5]. Therefore the understanding of the transportation network weak points (vulnerability) and its resilience to disasters is important in general and in particular critical for ensure the city security and safety.

We argue that in many instances transport infrastructure (network) spans other components of society and its reliability and performance have significant influence on services which are provided by the other city components (healthcare - health, business continuity and industry - economic, delivering disaster relief or facilitating mass evacuations - disasters, etc.). Therefore, a vulnerability analysis of transportation network in a resilient city concept should always be viewed in a broader context - with relation to geo-spatial, industrial, social context, etc.

Transport system as a part of resilient city concept

Transport systems are designed to have an operational performance and are expected to contribute to a city's overall sustainability. However, under climate change related hazards, the transport system is at risk of being in a failed state, either below its expected operational performance level, or unavailable all together [7].

Civil infrastructure such as roadways and rail lines in extreme weather conditions can be disrupted by impact of natural hazards as flood and landslide. High temperatures can trigger reductions in speeds due to rail buckling risk and overhead catenary sag. Both road and rail can be disrupted due to bush fire damage of infrastructure in high temperature and high wind events. Each of these can result in delays or suspension of transport services due to these localized effects [8].

Transport activity is the result of bringing together resources of quite a different nature: appropriate infrastructure, equipment, vehicles, trains, airplanes and ships need to be provided. Service providers put together these resources to make transport services available for different needs, thereby using different transport modes: rail, road, aviation, inland water or maritime shipping. Regulators at the various levels provide the basic rules to facilitate operations to run smoothly, efficiently and with minimum impacts.

The role of transportation in cities has layering principles. In operational view it is just transport citizens, cargoes, or something else with existing infrastructure from one place to another. However from strategical point of view it is more about building infrastructure, making land use plan, taking for consideration also environmental pollution and a lot of other issue. Resilient cities have to understand the requirements of stakeholders on transport systems from many perspectives. One of the most important is disasters perspective on which is focused next chapter.

Transport system and its role in disasters solving

Transport network is vulnerable to a wide range of hazards that may lead to a deterioration of its operating parameters and result in a crisis situation. These hazards and risks are associated mainly with external conditions affecting the transport network. Mentioned hazards are partially recognized as the effects of climate change. From disaster or crisis situation perspective resilient cities should be prepared to handle such a situation. Protecting vulnerable infrastructure against the potential effects of climate change is a vital part of a secure transport network strategy, however, it is not sufficient on its own [9]. Therefore a transport system must be able to adapt to hazards, so as to maintain an acceptable level of service.

Based on FUTURENET's methodology (see Fig. 1) the requirements for the crisis situation solving can be incorporated

into building of resilient cities in two aspects: (1) through transport planning and (2) resilience analysis.

Each threat can affect the capacity of the transportation network and/or produce demand on network (cause people to use transport network). Even if the transportation infrastructure is not directly affected during such incidents, it is important in providing of common services e.g. freight and package delivery, production processes ensuring, commercial and business travel, etc., it plays critical role in providing security for public e.g. emergency response - police, fire, medical services, armed forces, as it plays key role in delivering disaster relief, or facilitating mass evacuations (all these is transport demand). This could result in identification of the critical functions and assets which are critical for particular area (transport assets). During disasters increase the level of risk factors which result in unpredictable behaviour of people with following impact on transportation (transport behaviour). Therefore the ensuring of the required level of safety across the affected area (city) requires in some cases use of non-standard forces and resources, restrictions and grant specific duties which can vary depending on selected country e.g. restriction on freedom of movement and residence in the affected or threatened areas, limitation of integrity and privacy by evacuation to the designated place, no entry for vehicles or their use restriction, the command of civilian duty of maintenance of roads and railways, the traffic operability, etc.

Identification of critical transport assets condition, identification of susceptible services within transport demand, and consideration of transport behaviour in condition of climate change is essential for planning of appropriate programme within transport strategic planning cycle to achieve increased level of transport system resilience as well as increased level of city resilience itself. Strategic system planning should therefore consider and respect not only results of risk assessment but as well the results of resilience assessment of the city.

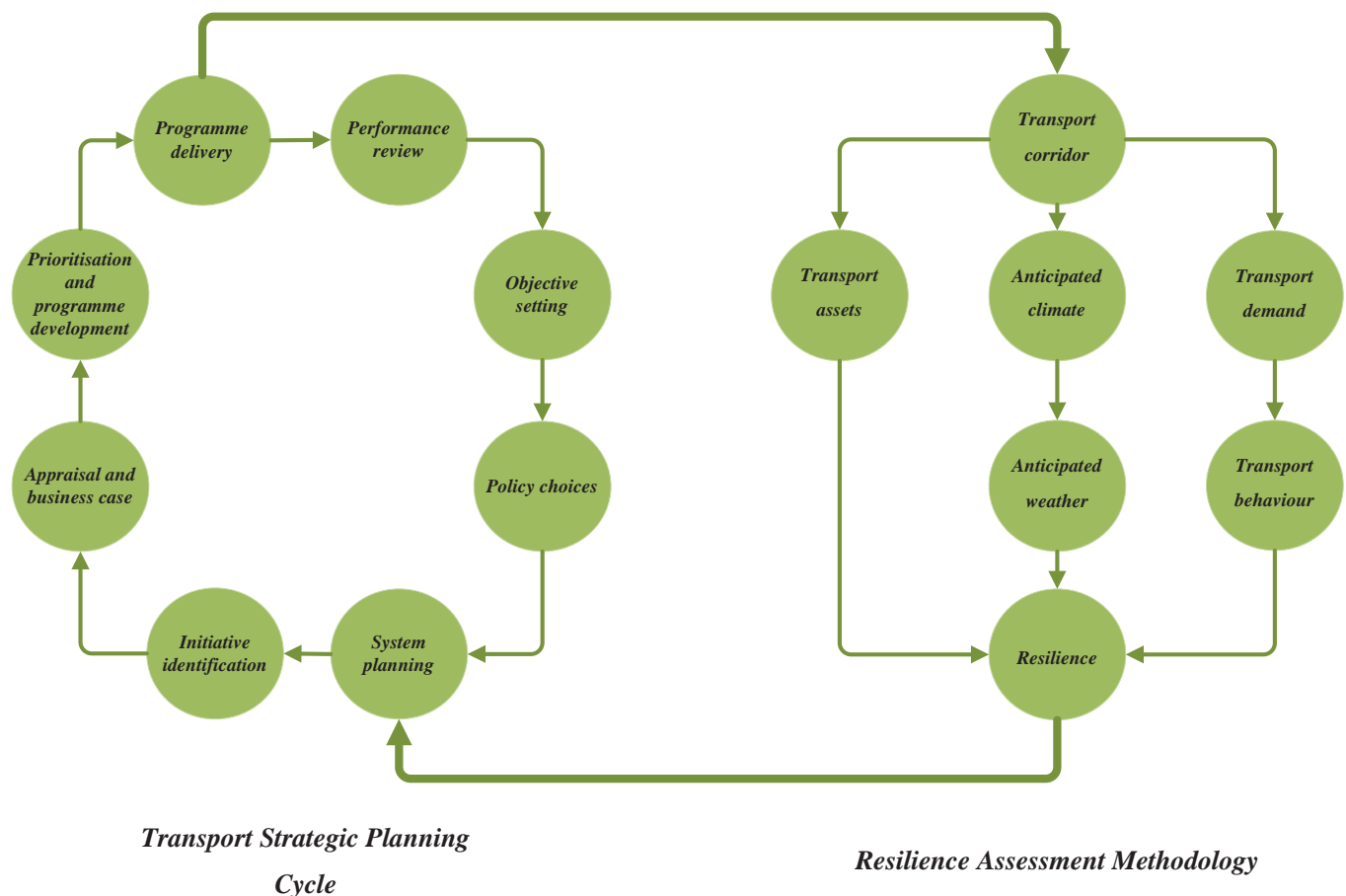


Fig. 1 The interface between the resilience assessment methodology and a typical transport strategic planning cycle [9]

Background and Rationale

There is no consensus on the definition of vulnerability. Basically it depends on subject area (context) in which the notion vulnerability is used. In the context of transportation network one can define the vulnerability as overall susceptibility to a specific hazardous event. It is also the magnitude of the damage given the occurrence of that event [10]. There is common agreement that the vulnerability in the context of transportation network represents a measure of loss of the transportation network's capabilities to perform its functions [11 - 13]. This agreement result in determining of transportation network most vulnerable points which can cause that performance loss. Such determination requires an assessment of the specific physical parameters of the transportation network elements as well as their close surroundings (e.g. bridge piers surrounding or roads subsoil).

Some authors [14, 15] argue that a system might be vulnerable to certain events but be resilient to others. Therefore is important take to account the specific risk and threat profiles to the area under analysis. Particular city areas with corresponding transport infrastructure elements can be on the one hand considerably expose to the danger of landslide because they are locate close to the steep slope but on other hand there is no danger of flood. There is also association with above mentioned requirements for assessment of specific physical parameters. In order to protect transportation elements, e.g. due to location within a flood area, can be performed e.g. hard (technical, construction) measures (pylons, barriers, etc.) which allow use these elements without limitations also in time of flood and this way decrease the sensibility of a particular element.

As the fundamental idea of resilience is derived from Ch. Darwin's research results who declares: „Not the strongest or the most intelligent will survive but a one who is the most adaptive“, the assessment of transportation network infrastructure vulnerability means that we should take into account also adaptive ability of the system under analysis. It can be seen as the ability of a system to change in a way that makes it better equipped to deal with external influences (disasters) [16]. Adaptive ability is also the combination of the strengths, attributes, and resources available to an individual, community, society, or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm, or exploit beneficial opportunities [17].

Based on above mentioned facts and partial conclusions a system or society that is highly exposed to a threat, susceptible to its effects and less able to adapt is more vulnerable. Following these relationships a vulnerability of transportation network in the context of the resilient city can be assess by considering three types of factors:

- disasters particularities and their impacts (ability of disasters cause dysfunction of transportation network elements) - exposure,
- characteristics of the transportation elements and its susceptibility to effects of a disaster - susceptibility,
- ability or capacity of transportation network in conjunction with society to adapt to changing conditions - adaptive capacity.

Vulnerability Core Factors

The newer vulnerability assessments [18, 19] also address various factors (in literature mostly called “core factors”) of vulnerability and their interplay such as linkages among exposure, susceptibility, and adaptation (see Fig. 2). Questionable is what should be the content of such factors.

Exposure

Following the EPSON CLIMATE project [20] and previous research [13] exposure refers to the nature and degree to which a system is exposed to climatic variations (it means exposure to change in climatic conditions) - for our case exposure of

transportation infrastructure refers to the possible effects and impacts of disasters. It depends also on the system's (transportation infrastructure) location - on spatial variations of assessed systems [21] as well as on disasters occurrence distribution in selected area. Refer to these facts we assume following characteristics as important.

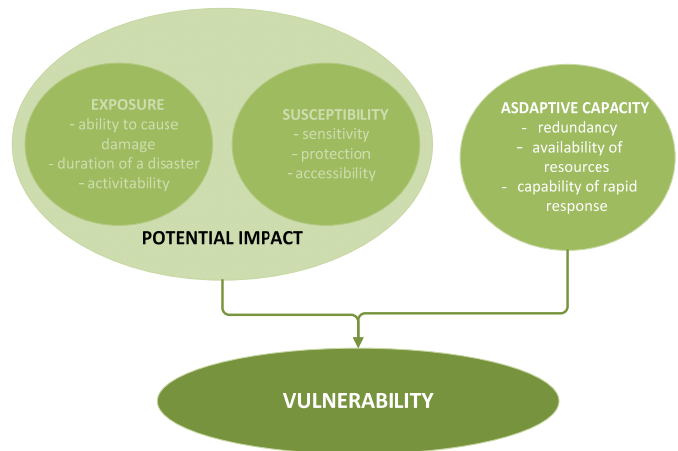


Fig. 2 Vulnerability and its core factors (Adapted from [18])

Ability to cause damage - is associated with an occurrence of particular crisis event and its intensity, type, mode of action, range and in overall with its destructive effects. E.g. earthquake with different intensity may have various destructive impacts. It also depends on the environment conditions in which it operates.

Duration of a disaster - is expected period of exposure to the effects of a disaster. It is also a period necessary to restore the required level of operational state of a transportation element. Increasing duration of a disaster indicates more severe consequences.

Activatability - means time necessary for threat activation. The longer this time period is, the less devastating a disaster could be. In cases with longer activation period it is possible to adopt some mitigation measures (e.g. warning, evacuation, makeshift dykes, enhancing resources and capacities, etc.). This argument cannot be apply across the board, e.g. in the case of a tornado it is not reasonably possible to be prepared to cope with such a disaster without impacts of a tornado (an evacuation is possible but it is not possible to make some hard construction measures). It results from destructive potential of a disaster and from limited resources for disaster prevention (resources could also be used inefficiently).

Susceptibility

As some authors [14, 15] argue that a system might be vulnerable to certain event but be resilient to the others. Our intention was to identify characteristics which reflect this fact. As important characteristics of susceptibility we assume (1) own ability of element to prevent and handle effects of disasters, (2) external ability of protection measures to help prevent or cope with effects of disasters, and (3) location of an element.

Sensitivity - is a tendency of a transportation element to be functionally damaged by effects of particular disaster. This characteristic is related to the ability of a transport network element to resist to and cope with expected negative effects on its own. It is based on an element construction parameters (robustness of construction, quality of materials used, age of construction, etc.). Critical infrastructure elements have characteristics and assumptions to better resist to the negative impacts of disasters.

Protection - it can be seen as additional feature to the “sensitivity”. “Sensitivity” is about own ability of an element to handle situation, on other hand “protection” take into account

external measure which are already applied on element or outside of element in order to protect this element, mainly with aim of decreasing the negative effects of a disaster. It include application of hard measures as dam construction, windbreaks, slope support, etc. as well as soft measures (security measures) which are applicable mainly against intentional crisis events (enhancing guarding of specific elements against terrorist threats, etc.).

Accessibility - is the level of simplicity with which an element of transportation network can be affected by a disaster. When it comes to natural hazards location of the property have to be taken into account e.g. flood area, tectonic area, area with possible landslides, etc.

Adaptive Capacity

Following literature review there is a close relationship between vulnerability, adaptive capacity and resilience and it is still not well articulated. According to previous research, resilience is an integral part of adaptive capacity [22]. Other concepts sees adaptive capacity as the main component of vulnerability [23] or as nested concepts within overall vulnerability structure [24]. In our approach for measuring vulnerability we understand resilience as integral part of adaptive capacity and adaptive capacity belongs to the core factors of vulnerability (see Fig. 1).

Taking into account definitions of adaptive capacity (see Background and Rationale) and according to research about resilience features in which resilient means robust (this is include in part "sensitivity"), redundant, resourceful, and capable of rapid response [25], core factor "adaptive capacity" could contain following parts.

Redundancy - is the ability of other elements of the system take over the functions of failed elements. In the perception of transportation network it means replacement impassable network segment by setting detours. Redundancy is closely linked to the density of the network and its structure. Dense transportation network offers more opportunities to replace an element. Therefore, there is a remarkable difference in redundancy of road and rail transportation network. From such point of view is rail network and its elements more vulnerable than the road elements. Moreover, particular network elements or network as whole may be unable to handle demand from other (others) inoperable network elements due to unsuitable structural features (weight restrictions, maximal traffic density, etc.).

Availability of resources - is access to the sources of city reserves or state material reserves which disposes with construction material for reconstruction of transportation elements or with spare parts for its immediate replacement (temporary bridge constructions, etc.)

Capability of rapid response - is ability of responsible authorities and rescue services (professional and voluntary) effectively (1) prevent effects of disasters by adoption of rapid measures (from coordination of traffic to building of makeshift dams) or (2) remove impacts of such events in short period of time and recovery to the previous state.

Vulnerability Index

For determination and calculation of final value of transportation network elements vulnerability we assume to use Vulnerability Index (equation 1). It represents an integration of all vulnerability core factors and their additional characteristics (from chapter 5). We argue that identified core factors and related characteristics have different influence on vulnerability final value. From that reason a weighted assessment of all factors and characteristics is assumed (multicriteria methods are suitable to use). We assume using specific value for vulnerability index calculation (e.g. from 1 to 5). Increasing values will indicate increasing vulnerability. The vulnerability index and interpretations of specific values (or probably it will be ranges of values) should serve for evaluation

of current state in specific city as well as for decision making purposes. Some recommendations for vulnerability reduction in terms of crisis planning, risk management and preparedness enhancing for decision makers should be also provided.

$$VI = f(E, S, AC) = f[f(CH_{ACD}, CH_{DD}, CH_{Ac}), f(CH_S, CH_P, CH_{Acc}), f(CH_R, CH_{AR}, CH_{CRR})] \quad (1)$$

where:

VI - Vulnerability Index, *E* - Exposure, *S* - Susceptibility, *AC* - Adaptive Capacity, *CH_{ACD}* - Characteristic - Ability to Cause Damage, *CH_{DD}* - Characteristic - Duration of a Disaster, *CH_{Ac}* - Characteristic - Activatability, *CH_S* - Characteristic - Sensitivity, *CH_P* - Characteristic - Protection, *CH_{Acc}* - Characteristic - Accessibility, *CH_R* - Characteristic - Redundancy, *CH_{AR}* - Characteristic - Availability of Resources, *CH_{CRR}* - Characteristic - Capability of Rapid Response.

If the given approach is applied on more elements or network parts simultaneously, it is possible to compare them and it allows the identification of more vulnerable parts. The responsible authorities should manage their reaction based on their current possibilities and with cooperation with crisis management representatives. They should apply some specific measures (hard or soft, or combination) based on particular hazard which should be addressed (e.g. different measures could be applied for floods or landslides). Moreover, by adopting specific measures authorities may also address and enhance unsatisfactory characteristics of vulnerability, e.g. we found out that the particular element is not redundant, but there is still option for construction of more dense network (add some links / roads to the network). Space for enhancing is mainly in core factor "adaptive capacity" and partially in "susceptibility" in which robustness (part "sensitivity") of transportation element can be enhanced. As was discussed, adaptive capacity and resilience are closely interconnected - they have common ground (common characteristics), and together with robustness built basis of resilience definition [25, 26].

In this point, an important relation (complementary relation) between resilience (resilient city concept) and vulnerability can be seen. By enhancing some parts (core factors or subsequent characteristics) of transportation network vulnerability, increased resilient of the city can be observed. On the contrary, by enhancing resilience characteristics, vulnerability of particular element or system can be reduced.

Conclusion

Within academic and also practitioners' communities there is no common agreement of vulnerability understanding in relation to resilience. However, this subject is active interest of both sides. In particular, understanding of vulnerability can help to identify weak components of a system (in our case - the city transportation network) and by adopting of suitable measures make a city more resilient to the impacts of disasters. In our research we assume complementary relation between vulnerability and resilient. Such connection offers enough space for application of vulnerability assessment results into the resilient city concept.

The article does not address possible domino effects which can occur in structural systems but it is only focus on individual vulnerability of transportation network elements. The article also does not discuss possible dependency or interdependency with other components of whole city system. In order to address these influences higher complexity of approach should be achieved. Complexity of approach could provide more accurate results but on the other hand could lead to unwelcome side effects as difficulty in understanding of approach and achieving results, time delays of results providing, overlapping of some features and effects, etc. This could lead to ineffective decision making.

We agree with opinion of Taylor and D'Este that it is not practical and cost-effective to undertake a geophysical or other risks assessment throughout the whole transportation network [11] - in our opinion also vulnerability assessment of all transportation elements. This is dictated by practical considerations - (1) the elicitation burden placed on experts whose knowledge is necessary to provide assessment should be limited; (2) importance of some infrastructure elements is significantly lower than the other ones. The proposed approach is intended to be applied to critical infrastructure elements, rather than to all transportation elements. The critical infrastructure elements in transportation can be identified by the experts through impacts based assessment approaches [27] or through simulations.

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